Small-scale Forest Economics, Management and Policy, 3(1): 1-15, 2004

Development Strategies for Privately Owned Forestry in the Mountainous Region of Sweden

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Forestry in Sweden as well as in other European countries is characterised by intense and increasing international competition resulting in decreasing roundwood prices in real terms. This is especially the situation in the mountainous region of Sweden with long transportation distances between the felling site and the processing industries located at the coast. The question arises whether forestry must be run more extensively than at present to achieve the optimal rate of silvicultural activities compared with the amount of timber cut. With this in mind, optimising economic analyses have been performed at the stand level as well as at the level of forest estates. Results of the analyses reveal that more intensive thinning (more frequent operations) and shorter rotation periods would increase profit and offset continuously decreasing roundwood prices. Intensive pre-commercial thinning (cleaning) is especially important for profitability of the subsequent thinnings and the final cut. The large number of cuts during the rotation will increase logging costs. However, this will be more than offset by the increasing production of economically matured dimensions of timber, an effect that will be still more pronounced when using new harvesting technology. Moreover, frequent high thinning operations (thinning 'from above' or removal of dominant trees) will result in more dense wood close to the pith, more evenly distributed year rings, and fewer and smaller knots in the lower part of the stem – in other words more valuable roundwood which will justify high transportation costs. Several biological and technical aspects of these treatment programs are discussed in the paper.

Keywords: forestry in rural regions, profitable silviculture, forest strategies, improved cut programs, high thinning, cleaning

INTRODUCTION

In the mountainous region of Sweden (the counties of Jämtland, the western parts of Västerbotten and Norrbotten), forestry is characterised by transportation distances for roundwood of 150 to 300 km from felling sites to processing sites situated along the coast. This is the case for all pulpwood and for most of the more valuable sawn timber. Moreover, the forest sites have low productivity because of a high altitude combined with Nordic latitudes. In view of increasing international competition on

the roundwood market, a question arises regarding which intensity in silviculture is the most efficient in this situation and under conditions of still lower prices of roundwood. Is the lowest possible intensity, without planting and cleaning (pre-commercial thinning or thin-to-waste but not weed control) and just cutting the naturally produced trees, the most profitable production alternative for private forestry in this mountainous region? These questions were studied in a research project undertaken on behalf of two research foundations, 'Norrskogs forskningsfond' and 'Brattåsstiftelsens forskningsfond'. The project has been reported by Eriksson (2002). This paper presents a condensed version of the analysis and findings.

The objective of the research was formulated as finding strategies for privately-owned forestry to cope with the low current price level of roundwood and a possible decrease of the price level in the future. Both silvicultural and cutting strategies were studied and stand level as well as forest estate level analyses were of interest. The study aimed to test the following hypotheses:

1. Forestry consisting of improved cutting programs will compensate for a price reduction of roundwood compared with traditional rules (recommended by the National Forestry Board 1988) at the forest estate level in the mountainous region of Sweden.
2. Establishment of stands by means of modern methods as regards scarification (mechanical ground preparation), planting and cleaning in the mountainous region of Sweden will lead to higher volume production. A consequence is higher profit at the stand level compared with the more common extensive methods advocated by the National Forestry Board.
3. Modern establishment of stands enhances the effect of improved cutting programs.
4. Interest rates above 2% cause forestry to be unprofitable in the mountainous region of Sweden.
5. Selective cutting methods are able to counteract reduced roundwood prices.
6. Cleaning is a highly effective way to increase the revenues from forestry. At the dominating site in the mountainous region of Sweden (of site index G18), more intensive cleaning than the stem densities recommended by the Swedish Forestry Board (1988) will be preferable.

METHOD OF COMPARING STRATEGIES

It is supposed that the goal of forestry is to maximise the net present value (NPV) of all future forest activities whether these are at the stand or forest estate level. Silvicultural methods are compared in terms of the increase in NPV per hectare compared with traditional forest management. Many methods have been developed to compare stand programs.

Methods Used for Economic Analysis of Stand Development

Studies on optimising profits from forest stands (i.e. maximising the NPV) have been published since the 1960s. Some of them used dynamic programming (Kilkki and Väsäinen 1969, Martin and Ek 1981, Ritters *et al.* 1982) and some linear

programming (Buongiorno and Michie 1980, Michie and McCandless 1986). Both methods seem to be able to optimise forest management. The former method, however, has restrictions as regards the number of variables which can be accommodated, but fixed costs may be represented conveniently. During the 90s multi-criteria decision models have been developed. When quantification of goals is possible, mathematical programming (i.e. LP or dynamic programming) can be applied (Dykstra 1984). Difficulties in expressing goals in mathematical terms have led to development of simulation models for decision support (Korhonen and Wallenius 1995). In this latter case the models are used for simulation of forecasts under varying circumstances as prescribed by the decision maker. Aspects not represented in the model, such as environmental restrictions, may then be taken into account by the participating decision maker.

The Model Used in This Study

The decision problem in this study is to maximise the NPV generated from stand and forest estate management. Simultaneously, it is necessary to regard aspects such as not reducing the stem density in a dense stand too rapidly because of the risk of snow damage, and not performing too many thinning operations because of fixed costs and the increasing risk of root rot and physical stem damages. The solution of the management problem also must take account of questions of effects on unquantifiable wood properties. A simulation model has been used to calculate and describe consequences of defined management programs.

In the model, stand development is predicted by Söderberg’s (1986) functions of single trees for undisturbed development complemented by Jonsson’s (1974) functions of effects of thinning treatments. Development of stands from both planting or natural regeneration is predicted by means of Pettersson’s (1992) functions showing tree growth and development of stem diameter distributions at varying initial stem densities, tree species and cleaning (pre-commercial thinning) programs. Effects of natural thinning (Bengtsson 1980) as well as the in-growth of naturally regenerated trees are considered by annual relative changes in stem numbers. Calculations of stand development as well as the profitability of cutting programs are performed by means of a simulation model developed by Eriksson and Eriksson (1993).

The model starts with a stem distribution at the age of about normal first thinning measured in real stands or generated by a model for description of young stands (Pettersson 1992). Tree growth by species is simulated through the first ordered thinning, described by thinning intensity and form as well as the time point of thinning, and continuing on until the final cut. At each thinning or harvest, cut trees are cross-cut (cutting into lengths), the logs are evaluated, and the cost of treatment is calculated. The ground value is added to the harvest value to account for earnings from future land uses. All the net values are then discounted to the time-point of management decision. Most of the routines referred to above are programmed in Fortran. For each alternative in a single stand (one of a number of stands in a forest estate), these calculations are repeated until a near optimal solution has been identified. Ground value is calculated as the net present value of the best management program applied in an endless sequence of rotations on the specific site and using the actual interest rate.

Assumptions of the Simulations

A real rate of interest after taxes of between 2% and 2.5% is used in this analysis. In Swedish forestry, as in the forestry of many other countries, the growth in the living stand is not taxed (not to be confused by a fixed annual tax, independent of actual growth) until the capital is realised by cut, to be compared with the annual revenue from capital on a bank account which in Sweden is taxed at 30%. During the rotation of a forest stand a tax debt is built up by the non-payment of annual tax (compared with the tax on a bank account). The tax debt is used for growth in the forestry, which will give a lower interest rate applied on investments in forestry. Under the assumption that the net revenue from the cut is real as far as increasing timber prices and adjustments of costs in forestry counteracts a general economic inflation (the national inflation goal is 2%), an interest rate of 2% will correspond to a required interest rate on a bank account of: ((1.02*1.02)-1)/(1-0.3)=.058 or 5.8%, while an interest rate in forestry of 2.5% corresponds to ((1.02*1.025)-1)/(1-0.3)=.065 or 6.5% on a bank account. In other words, an interest rate between 2% and 2.5% from an investment in forestry is capable of competing with alternative interest rates outside forestry. The general effect of the tax rules applied on forestry in Sweden (and apparently in many other countries) is that investment in forestry is promoted compared with investment in other areas.

The costs of forest operation and the revenue from roundwood, adjusted for the transportation to processing sites, are calculated taking an average of cost and wood price data for the period 1997 to 2001. The figures refer to Vattudalen's forest management area situated in the county of Jämtland at an approximate altitude of 300 m. This management area is operated by the forest owner organisation Norrskog. The area is, by the staff of the organisation, regarded as a typical district situated in the mountainous region of Sweden. Sensitivity analyses have been performed on prices of roundwood (sawn timber as well as pulpwood) by price reductions of 10% and 20% to reflect the effect of less favourable future competition situations. In the less probable situation of higher roundwood prices it is assumed that a more intensive forestry than discussed in this paper will be the consequence. Allowance is made in the cost of thinning in spruce stands for the cost of protection against root rot (*Heterobasidium annosum*).

Performance of the Analyses

The starting point for the selection of the most profitable management program (the improved program with the highest NPV) is based on results generated by an optimising version of the simulation model reported by Eriksson and Eriksson (1993) and Eriksson (1994). By changing the performance of the thinning program for different rotation periods (management program), an approximately optimal program may be selected. For the chosen 'optimised' program no increase in NPV higher than 0.1% could be found by changing any single variable such as thinning strength by 5%, thinning form by 5% or the time of thinning by 5 years.

The above hypotheses are tested by simulation of the development of forest status as well as of silvicultural treatments and cutting operations of a traditional forest management system as compared with an improved management program of the forest simulated in a similar way. The simulation results are regarded as deterministic values. These values, however, are represented by calculated growth from functions estimated on data from a national forest survey and by wood prices

and management costs derived from a defined time period. The deterministic values represent average forestry situations.

The stands modelled in the calculations are generated in three distinct ways in order to illustrate effects in special situations or of specified treatments. These are:

	Kind of stand generation	Motivation
1	Use of randomly selected stands	Show effects on forestry in general
2	Inventories of young stands	Show effects on well established stands
3	Simulations of young stands based on cleaning experiments	Show effects of cleaning alternatives

The first way is to gather data from randomly chosen stands to show effects of silviculture and cutting programs applied on forests in general within the mountainous region. Such data have been obtained from the National Forest Survey for this study. Based on these data, a forest estate was constructed, the area of which was 100 ha of productive forest of Norway spruce (*Picea abies Karst*) with age distributed evenly across age classes between 0 and 120 years. The site index class was assumed to be G18, i.e. the dominant height at 100 years will be 18 m in accordance with the Swedish Site Index Class System. The class G18 corresponds to an average, annual, ideal volume production of 3.3 m^3/ha including bark and above the stump. Each age class is represented by a number of classes of stems per hectare (sph) and, from the inventory material, a basal area weighted average diameter under bark is calculated. From these data, diameter distributions have been constructed, which form the basis for simulation of single-tree growth, harvesting and calculation of net values when cut.

The second type of stand data used in this study emanates from inventories of young stands with known establishment methods, characterised by intensive scarification of the planting site (by burning because of the thick humus layer), and planting of genetically improved material. An empirical experience is that these kinds of stands show rapid growth, which has not declined about 40 years after planting.

The third stand generation method used in the analyses is simulated by functions developed from data on cleaning experiments reported by Pettersson (1992). Using this method of stand generation, the relation between cleaning to varying stand densities and the following diameter distribution in the stand before first thinning is given and, as a consequence, the effect of cleaning on the profitability of the thinning program can be obtained.

As a reference, all analyses are compared with treatments based on schematic rules recommended by the National Forestry Board (1985). These rules may be described as consisting of a few low thinning operations (one or at the most two on a G18 site), followed by a long growth period before a final cut where most of the wood produced is harvested.

FINANCIAL PERFORMANCE UNDER MANAGEMENT ALTERNATIVES

Analysis on Randomly Selected Stands

As a first step, analyses were performed based on data from the National Forest Survey to investigate the hypothesis that forestry using improved cutting programs will compensate for a reduction in the price of roundwood. Some characteristics of the forest estate developed from the data are presented in Table 1. Management of the forest defined above was simulated under the schematic rules recommended by the National Forestry Board (1985), to provide a reference performance level. The simulation results of a traditional cut are reported in Table 2.

Table 1. Status of a forest estate of Norway spruce at 300-500 m.a.s.l. and ideal average production corresponding to site index class G18

Age (yrs)	Area (ha)	Site index m^3/yr/ha)	Ideal average production (m^3/year)	Stem density (sph)	Mean diameter (cm)	Basal area (m^2)
10	8.33	3.3	27.50	0	0	0
10	8.33	3.3	27.50	0	0	0
30	4.17	3.3	13.75	500	10.8	3.9
30	4.17	3.3	13.75	700	10.8	5.5
30	4.17	3.3	13.75	1200	10.2	7.3
30	4.17	3.3	13.75	2000	11	14
60	11.11	3.3	36.67	700	20.1	21.8
60	11.11	3.3	36.67	1200	17.5	26.8
60	11.11	3.3	36.67	2000	16.2	35.3
100	11.11	3.3	36.67	700	21.1	24.1
100	11.11	3.3	36.67	1200	19	32.8
100	11.11	3.3	36.67	2000	17.3	42.6

Total area (ha):	100
Total site index production, (m^3):	275
Average standing, volume (m^3/ha):	148

Attempts to increase the NPV in the improved program in accordance with the method described resulted in different kinds of programs depending firstly on stem density and secondly on average diameter at breast height (dbh). A small diameter at the time point before the first thinning and high stand density (the recommended density in stems per hectare), result in a first thinning from below (low thinning), between two and three thinnings from above, and a relatively long rotation period. Fewer initial stems and greater diameter favour fewer thinnings, now performed from above and combined with a shorter rotation. This last program normally leads to the highest NPV. The improved cutting programs are presented in Table 3.

Table 2. Effect on NPV of traditional cutting program, Norway spruce at 300-500 m.a.s.l..

Vol per ha (m^3/ha)	Total volume (m^3)	No of thinnings	Rotation length (years)	NPV (kSEK/ha)	Total NPV (kSEK)	NPV -10% (kSEK/ha)	Total NPV (kSEK)	NPV -20% (kSEK/ha)	Total NPV (kSEK)
0	0			0	0	0	0	0	0
0	0			0	0	0	0	0	0
23	96	1	105	18	75	15.6	65	10.3	43
223	929	1	105	23.1	96	20.0	83	14.6	61
30	125	1	115	19.8	83	17.0	71	11.2	47
61	254	2	115	27.2	113	23.3	97	20.00	83
150	1667	1	120	31.9	354	27.7	308	24.1	268
171	1900	1	120	27.2	302	23.1	257	21.7	241
213	2367	1	120	25.8	287	21.5	239	19.2	213
174	1933	0	120	30.5	339	26.4	293	22.2	247
227	2522	0	120	30.9	343	26.5	294	22.00	244
275	3056	0	120	26.8	298	22.3	248	17.8	198

Performance measure	Level	Difference at unchanged price (kSEK)	Difference at unchanged price (%)
Total volume (m^3):			
Total NPV at unchanged r.w.[a] price (kSEK) [b]:	2290		
Total NPV at r.w. price reduced by 10% (kSEK):	1955	-335	-14.6
Total NPV at r.w.price reduced by 20% (kSEK):	1645	-646	-28.2

a. r.w. refers to roundwood.
b. kSEK7.5 corresponds to US$1,000.

Applied on a 100 ha forest estate, the improved alternative increases the NPV from 2,290 to 2,736 kSEK (20%) compared with the recommended scheduled program. If the price of roundwood is decreased by 10% and 20%, the NPV will decrease by about 15% and 28%, respectively, for both traditional and alternative cutting programs. The larger decrease in NPV compared with the change in price may be explained by the high level of fixed costs that must be covered in all alternatives. A change into alternative management will compensate for a price reduction up to about 12%. Traditional forestry practices are in other words not optimal.

Analyses of forest estates on poorer sites (at higher altitude) do not show such a response as at 300-500 m as regards increase in NPV of the improved cutting programs because the longer rotation periods in scheduled programs are in closer harmony with natural growth conditions

To sum up, improved cutting programs applied on forests in general will compensate for a roundwood price reduction of 12% on index G18 sites in the mountainous region of Sweden. Applied on poorer sites, the response of improved cut will be less pronounced.

Table 3. Effects on NPV of improved cutting program of Norway spruce at 300-500 m.a.s.l.

Vol. per ha (m^3/ha)	Total volume (m^3/ha)	No of thinnings	Rotation (years)	NPV (kSEK/ha)	Total NPV (kSEK)	NPV per ha -10% (kSEK/ha)	Total NPV -10% (kSEK)	NPV per ha -20% (kSEK/ha)	Total NPV -20% (kSEK)
0	0			0	0	0	0		0
0	0			0	0	0	0		0
23	96	2	80	21.4	89	18.5	77	15.9	66
223	929	2	80	25.8	108	22.3	93	19.1	80
30	125	3	95	26.1	109	22.3	93	18.9	79
61	254	5	90	28.4	118	23.7	99	19.6	82
150	1667	3	100	38.9	432	33.6	373	28.4	316
171	1900	4	120	37.9	421	32.4	360	26.9	299
213	2367	5	135	34	378	28.4	316	23.4	260
174	1933	2	130	31.6	351	27.2	302	22.7	252
227	2522	2	130	34.6	384	29.5	328	24.4	271
275	3056	3	140	31.1	346	25.8	287	21.3	237

Performance measure	Level	Difference at unchanged price (kSEK)	Difference at unchanged price (%)
Total volume (m^3)	14849		
Total NPV at unchanged r.w.[a] price (kSEK	2736		
Total NPV at r.w. price reduced by 10% (kSEK)	2327	-409	-14.9
Total NPV at r.w. price reduced by 20% (kSEK)	1941	-795	-29.1

a. r.w. refers to roundwood.
b. kSEK7.5 corresponds to US$1,000.

Analysis on Inventoried Young Stands

To provide a contrast with the data from the National Forest Survey, six young stands of Norway spruce aged between 30 and 50 years of known establishment method were inventoried. The purpose was to derive guidelines about the management of stands established with modern methods. Ten randomly oriented circular plots per stand were inventoried in the stands. Each stem was measured by calliper and heights of a proportioned selection of trees were measured. Stands 1, 2, 3 and 6 had been planted after burning, and Stand 4 was naturally regenerated under a shelterwood of Birch (*Betula pubescens*), whereas Stand 5 is managed by so called 'mountainous selective cutting'. This is a continuous cutting method, characterised by repeated thinnings from above each fifteenth year and by natural regeneration complemented by planting.

Financial performance data are presented in Table 4. This table also reports effects on NPV of various cutting programs relative to the traditional program. In Stand 5, a continued selective cut is compared with a traditional schematic cut.

Stand 1, with 1741 sph, will give the highest NPV if low thinned the first time followed by two high thinnings and a final cut in year 105. This gives a NPV of 23.4 kSEK at 30 years (the time point of stand measurement) and 2% rate of interest, as compared with 17.3 kSEK for a traditional program consisting of one low thinning and a final cut at 110 years. An improved program gives an increase in NPV of 35%. An increase in the rate of interest up to 2.5% will reduce the NPV by 24% to 17.9 kSEK. A similar degree of change in NPV at a higher rate of interest arises for the other stands.

In Stands 2, 3, 4 and 6, thinning from above only is to be preferred, which will still give a greater increase in NPV compared with the traditional program. In Stand 4, this increase in NPV of the improved program is as high as 95%. A reduction in the roundwood price by 10% and a rate of interest of 2.5% will decrease the NPV by about 35% in these five stands.

NPVs under the various cutting programs discounted to the age of inventory in each stand are reported in Table 4. The NPVs are calculated at unchanged roundwood prices and prices decreased by 10% and at interest rates of 2% and 2.5%. The following cut programs are applied to the stands:

Traditional: Scheduled cutting program based on recommendations from the National Forestry Board, consisting of one or two low thinnings followed by clearcut.

Improved: Cutting program consisting of one initial low thinning if high stem density, then frequent high thinnings and an earlier clearcut compared with traditional program.

Selective: Cutting program applied on Stand 5 consisting of repeated high thinnings in harmony with stand development.

It seems that the increase in NPV of improved programs is connected with:

a) high growth in the stands caused by intensive regeneration such as scarification and planting of genetically improved material
b) low initial stem numbers in the inventoried stands; and
c) a long influence during the rotation of the improved program.

Table 4. Financial performance of various cutting programs

Stand name	Stem density	Total age	Stem volume	Cutting program	1st thinning		2nd thinning		3rd thinning		4th thinning		Clear cut		NPV +/-0		NPV -10%	
	(sph)	(yr)	(m^3/ha)		(yr)	(vol. m^3)	(yr)	(vol. m^3)	(yr)	(vol. m^3)	(yr)	(vol. m^3)	(yr)	(vol m^3)	(kSEK/ha)		(kSEK/ha)	
															2%	2.5%	2%	2.5%
1.Tjärnt.	1741	30	42	Improved	40	49	60	58	80	68			105	248	23.4	17.9	19.7	15
				Traditional	50	72							110	363	17	12.3	14.5	10.3
2.Kålbod.	1063	30	50	Improved	40	57	55	62	70	73	90	83	105	256	33.1	26.4	28.2	22.5
				Traditional	50	84							110	423	18.7	14	15.7	11.7
3.Gåjeb.	1489	35	52	Improved	45	50	65	59	85	71			110	255	23.4	18.2	19.7	15.3
				Traditional	50	56							110	319	13.2	9.6	10.9	7.8
4.Sällsjöv.	1120	30	50	Improved	55	108	70	78	85	82			105	278	34.5	27.3	29.8	23.5
				Traditional	50	84							110	416	17.7	13.5	14.8	11.4
5.Gävsj.	617	50	38	Selective	65	37	90	43	115	50	140	49	160	142	8.4	6.8	6.8	5.5
				Traditional									95	214	7.8	6.4	6.6	5.2
6.Vilhelm.	1069	30	38	Improved	45	54	60	68	75	67			95	227	28.5	23.1	24.5	19.8
				Traditional	50	63	75	84					110	303	17.6	13.9	14.8	11.7

The most extensive cutting program in Stand 5, the selective cutting program, gives low NPV, 8.4 kSEK, but because of low establishment costs is insensitive to reduced roundwood prices and high rate of interest. A reduction in the roundwood price by 10% and a 2.5% rate of interest will decrease the NPV by 35% to 5.5 kSEK. Because the silvicultural costs are reduced to one complementary planting each fifteenth year, it follows that the economic viability is robust but on a low level.

Calculations also show that the NPVs discounted to year 0 of the inventoried stands will cover the costs of scarification, planting including restocking of blanks and cleaning, 6.9 kSEK, in all cases, with the exception of Stand No 3, when a scheduled cutting program is used (Table 5). The selected cut Stand 5 has never been regenerated artificially.

Table 5. NPVs from six inventoried young stands

Stand number	Age of inventory (years)	Traditional program		Improved program	
		NPV at the age of inventory (kSEK)	NPV at year 0 (kSEK)	NPV at the age of inventory (kSEK)	NPV at year 0 (kSEK)
1	30	17.3	12.9	23.4	9.6
2	30	18.7	10.3	33.1	18.0
3	35	13.2	6.6	23.4	11.7
4	30	17,7	9.8	34.5	19.0
5	50	7.8	2.9	8.4	3.1
6	30	17.6	9.7	28.5	15.7

The following is a summary of the analyses on inventoried young stands:

a) intensive establishment such as scarification and planting of genetically improved material (represented in the model by the more developed initial status of the stands) produces higher profit (in terms of NPV) even when the price of roundwood falls or the rate of interest increases (within the tested limits);
b) the combination of intensive establishment and improved cutting programs is an efficient way of counteracting international competition, for forestry in the mountainous region of Sweden; and
c) selective cutting combined with natural regeneration and complementary planting leads to low risk of a negative NPV, but also reduces the probability of a high financial return.

Analysis of Young Stands Generated on the Basis of Cleaning Experiments

A third step embraced analyses based on data from cleaning experiments. The objective was that hard cleaning is an efficient way to increase the revenue from forestry even in the mountainous region of Sweden.

It was shown above in the analyses of inventoried young stands that improved cut programs result in higher NPV when applied to stands with relatively few stems per hectare. The question arises of the effects of a change in the initial stem density from the recommended 1600 sph to 2000 sph or 1200 sph. The 2000 level or higher is in

practice often the result after planting in combination with natural regeneration. The low level, 1200, is more seldom practised but might lead to a higher NPV.

Figure 1 shows the volume development after cleaning to 1200 sph in a stand of Norway spruce on site index G18. The scheduled program with two thinnings from below and a final cut at 130 years gives a larger standing volume per hectare than the improved program consisting of three high thinnings and a final cut at 115 years. The development of stem density after the two programs is shown in Figure 2.

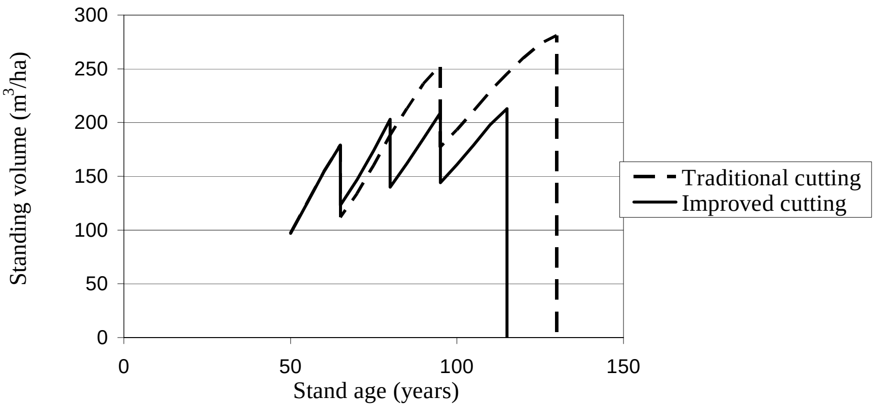

Figure 1. Volume development after cleaning to 1200 stems per hectare

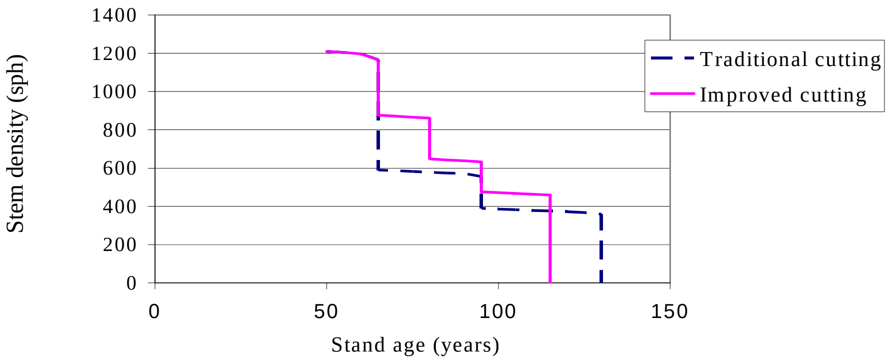

Figure 2. Stem density (stem volume including bark over stump) development after cleaning to 1200 stems per hectare

In Table 6 the NPV is shown when cleaning to stem densities of 1200, 1600 and 2000 sph. The results emanate from analyses in stands of Norway spruce at site index G18. The scheduled program reduces the stem density more by means of the two low thinnings than does the improved one. This results in a large volume on a few large trees with a low rate of interest in the scheduled program. The improved program with slightly higher stem density and smaller trees leads to a NPV of 28.9 kSEK compared with 23.0 kSEK in the scheduled program. Similar effects have been studied for cleaning to 1600 and 2000 sph. It is obvious that cleaning to 1200 sph in a stand of Norway spruce on a site of index G18 will give markedly higher

NPV than cleaning to 2000 sph. The NPV of the former is 8.2 kSEK or about 30% higher in the improved alternative.

Table 6. Net present values in kSEK at scheduled and improved cutting programs

Cut program	Cleaning intensity (sph)		
	1200	1600	2000
Scheduled	23.0	10.5	15.8
Improved	28.9	24.3	20.7

DISCUSSION

Three kinds of stand (or forest estate) data have been analysed. Analysis of stands based on data from the national forest survey indicates that there is a clear potential to improve forest management in general. The analysis of the six inventoried young stands reveals that well established stands increase the potential of improved management markedly. Simulations on theoretically generated stands based on cleaning experiments show that an early and strong reduction of stand density in stands of Norway spruce by cleaning will increase the profit in the following thinning program substantially. In other words, the profit of improved management programs is high in the short perspective but will be still better if combined with proper establishment and cleaning in the young stand.

The above results only refer to effects on NPV which can be quantified. The analysed management programs also give rise to effects that are not so easy to evaluate. One such effect is the risk of attacks of root rot (*Heterobasidium annosum*), which will be higher in cutting programs with numerous thinning operations. Consequently, all thinning is evaluated with the inclusion of costs for protection against root rot.

Another problem connected with the form of thinning is the influence on wood properties. Many studies give preference for high thinning as regards properties such as dense year rings, a small proportion of juvenile wood close to the pith, small branches and branch-free wood. These properties, desired in constructions that require form stability and strength, are well rewarded in the market and lead to greater financial viability of forestry characterised by long transportation distances.

Studies of wind and snow damage in stands give varying results as regards the thinning form. Some have found that low thinning is the best way to avoid such damages and some that high thinning is the best method. A low risk of wind damage and snow damage is probably achieved by an initial stem reduction by cleaning or low thinning when starting from a dense stand, which corresponds to the recommended treatments of this study.

At the end of the rotation the frequent thinnings in the improved programs produce a shelterwood system that has both desirable and undesirable properties. Favourable characteristics include the positive effects on landscape appearance, improved possibilities for berry picking, low flow of nutrient into lakes and watercourses, possibilities for natural regeneration, and a stable environment favouring species in fauna and flora sensitive to disturbances. Also, the risk of damage caused by frost and insects will be reduced. The shelterwood will thus

facilitate the regeneration and reduce the growth of young plants, which will improve the wood properties in the new stand. However, the shelterwood is a hindrance to efficient logging. The new stand under the shelterwood will in according to some studies not be as productive as a planted stand after a clear-cut. These further aspects should be considered in evaluating the performance of treatment programs in the mountainous region of Sweden. The choice of methods for the final cut and regeneration of new stands are the subject of an intensive debate in Sweden and the other Nordic countries.

CONCLUSION

When applied on forestry within the mountainous region in Sweden, improved cutting programs will lead to higher profit than traditional scheduled programs in a situation with reduced prices of roundwood. Characteristics for such improved programs are that small average diameter at the time of the first thinning and many stems per hectare favour a first thinning from below (mainly suppressed trees will be removed). The remaining thinnings will be performed from above (mainly dominant trees on average will be removed), and a long rotation period. In addition to these rules, sick and damaged trees and trees with low value as regards wood characteristics will be removed from the stand. When stand density is relatively low and average diameter high, lighter thinning performed from above, combined by a shorter rotation, will lead to the highest NPV. This last program, indicating a severe cleaning before the commercial thinning period, is normally the preferable alternative from an economic point of view.

The purpose of the improved program is to produce commercial dimensions of roundwood rapidly and in large amounts. This will be achieved by reducing the stem density compared with the recommended level by low thinning and then performing high thinning until the last stems are finally cut at acceptable dimensions. This improved method will be most efficient in stands established by modern methods of scarification, planting and cleaning. Natural regeneration in combination with selective cutting leads to low but stable revenue, robust to negative price trends in forestry.

Intensive cleaning is a most beneficial method in a situation of decreasing roundwood prices. Extensive forestry as regards regeneration, cleaning and thinning is not recommended to counteract reduced roundwood prices within the studied limits.

The results are strongly dependent on the chosen interest rate. There is a strong argument to use a low interest rate under the Swedish tax systems. An interest rate of 5%, for example, applied in the mountainous region of Sweden would indicate that a very extensive, low-input forestry system is required for financial viability.

ACKNOWLEDGEMENTS

The author thanks the two research foundations of Norrskog and Brattåsstiftelsen, which have financed the research project. Professor Ljusk-Ola Eriksson has given valuable support to the analyses by means of his simulation model. Dr Steve Harrison has provided many helpful comments in order to improve the paper.

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